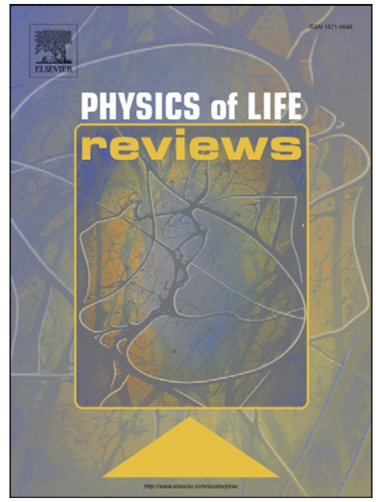
Accepted Manuscript



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PII: S1571-0645(13)00161-9
DOI: 10.1016/j.plrev.2013.11.003
Reference: PLREV 426

To appear in: *Physics of Life Reviews*

Received date: 5 November 2013
Accepted date: 5 November 2013

Please cite this article in press as: Reimers JR, et al. The revised Penrose–Hameroff orchestrated objective-reduction proposal for human consciousness is not scientifically justified:. *Phys Life Rev* (2013), http://dx.doi.org/10.1016/j.plrev.2013.11.003

The Revised Penrose-Hameroff Orchestrated Objective-Reduction Proposal for Human Consciousness is not scientifically justified: Comment on "Consciousness in the Universe: A Review of the 'Orch OR' Theory" by Hameroff and Penrose

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The article: "Consciousness in the Universe: A Review of the 'Orch OR' Theory" by Hameroff and Penrose [1] reviews work [2-5] concerning a proposal for the origin of consciousness by Penrose [6, 7]. This model postulates that microtubules can sustain long-lived quantum states and support quantum information processing associated with the effects of quantum gravity ("Orch OR").

For quantum information processing one must have quantum information storage units such as *qubits*. All aspects of the proposal need to be considered in terms of how they either influence or are influenced by the properties of these storage units. For example, the involvement of quantum gravity in the manifestation of consciousness would need to be described in terms of how quantum gravity affected the operation of these qubits, as would any other effect that could impact on macroscopic neural processes, and the influence of any dynamical process taking place in, on, or around the microtubules.

In the current review Hameroff and Penrose suggest that the qubit could be either: (a) "interactive dipole states of individual tubulin proteins" such as "London-force dipoles" or (b) magnetic dipoles or (c) nuclear spins. "London force electric dipoles" have been discussed in previous publications but the other two options have been introduced for the first time. Previously, Hameroff and Penrose had also proposed that conformational switching could produce coupled electron-vibration qubits but this claim is withdrawn in the current review.

The London force is of quantum-mechanical origin. An instantaneous fluctuation of the electronic distribution creates a dipole in one molecule that in turn induces a dipolar response in a neighbouring molecule. This leads to a net attractive force. The key feature is that these electric dipoles are *fluctuations*, not *states.* Individual *states* are needed to construct a qubit, and the review makes no attempt at specifying how qubit states could be associated with these London fluctuations. Further, it is not explained how the magnetic dipole states could be constructed or how these states could be decoupled from the nuclear motions so as to achieve extended quantum coherence. No suggestion is made as to how states associated with nuclear spins in magnetic fields could be utilized as qubits in situ in microtubules, and the nuclei supposedly supporting the states are not named.

No model of Orch OR can be treated seriously without the following:

(i) a precise description of the quantum states of the qubit,

(ii) a description of the mechanism through which the wavefunctions representing these states become entangled, including specification of the basis in which measurements of the qubit's properties are performed in situ, and

(iii) a means of achieving quantum coherence over the required time scale.

Hameroff and Penrose provide only a vague set of qubit possibilities. By not specifying the qubits in the current review they fail to provide a means by which the postulated links between quantum gravity and conscious behaviour could be assessed. In previous versions of Orch OR, they *did* define a qubit that at the time might have been considered a reasonable proposition to advance and test. They proposed that conformational switching produced a couped electron-vibration qubit that interacted with the cellular environment through associated large changes in microtubule structure and with quantum gravity via the significant mass displacement associated with the vibration. Coupled electron-vibration qubits are indeed considered as possibilities for use in modern quantum information technologies [8-10]. Quantum coherence was postulated to be provided by Fröhlich condensation [11-13], a predicted but unobserved macroscopic quantum effect. The original proposal thus contained a critical testable hypothesis.

We tested this hypothesis and found two fatal shortcomings, resulting in it being withdrawn from Orch OR in this current review. First, we showed the conformational-switch was not a vibration, as is required for the qubit, but instead involves an irreversible chemical reaction [14]. Second, we examined the postulate that Fröhlich condensation could deliver unprecedented quantum coherence in a qubit involving electronic motion [15]. Whilst Fröhlich proposed that the coupled non-linear equations that he solved would show *Bose-Einstein*-like behaviour, we found that instead a Fröhlich condensate would be *extremely incoherent*. Further, we showed that significant *classical* effects of Fröhlich condensation did not manifest unless the system was very far from thermal equilibrium, with component parts needing to be at temperatures in excess of 500 K for room-temperature operation. Fröhlich condensation could not sustain quantum coherence in biological systems and could not support Orch OR. We also note that the observed decoherence times for quantum processes involving electronic motion are usually in the range of 10 fs to 30 ps. A qubit with dynamics even slightly coupled to electronic motion would not retain quantum coherence on the 25 ms timescale required for Orch OR which Hameroff and Penrose suggest in this current review. This has consequences for all proposed qubits.

In an effort to perpetuate their model they now include “electron-cloud dipoles (London forces)”, magnetic spin dipoles and nuclear spins in a list of possible qubits, without suggesting how any of these phenomena could in fact be used to make a relevant qubit. The review is thus neither self-consistent or scientifically coherent and violates the basic tenants of good scientific practice [16]. The specification of the quantum qubit should be the centrepiece of the proposal. All other aspects of the Orch OR proposal are only relevant in terms of how they affect the qubits. Without a viable qubit specification there is no connection between the proposal and the observations of Bandyopadhyay and others. Without a qubit there is no connection to postulated effects of quantum gravity. Without a qubit there is no testable hypothesis linking together the phenomena of quantum gravity, elementary biochemical function, and consciousness, and no basis on which "Orch OR theory" can be considered as a proposal worthy of further consideration.

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